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Prepared in cooperation with Novelis Global Technology Centre and Honeywell Electronic Materials.

14. ABSTRACT

A new conceptual design of ECAE die for plate billets was developed and tested. The die provides semi-continuous processing "pass-by-pass" without reshaping and preheating, satisfies conditions of industrial operation, and presents potential to scale up ECAE for bulk plates and sheets.
The new processing technology "ECAE + warm rolling" was demonstrated for aluminum armor alloy AA 5083. High strength armor plates (YS = 397 MPa, UTS = 446 MPa, EL = 10%) were delivered to the Army Research Office for ballistic testing.
ECAE rolled products were also tested for superplastic forming, precision bulk forging and sheet metal forming. Superior technical characteristics were obtained in all cases. Material degradation during Friction Steer Welding confirmed necessity for fabrication of full scale armor plates.

15. SUBJECT TERMS

Key words: ECAE, die, worm rolling, light alloy armor, superplastic forming, precision forging, sheet metal forming.

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Title

Fabrication of High-Strength Lightweight Metals for Armor and Structural Applications

Description and Anticipated Benefits

Engineered Performance Materials in conjunction with its collaborators at Honeywell Electronic Materials and Novelis Global Technology Centre has successfully performed programs of Basic and Optional Plans.

In accordance with the Base Plan, a new conceptual design of ECAE die for plate billets was developed providing effective semi-continuous processing “pass-by-pass” and satisfying conditions of industrial operation. The die presents potentials to scale up ECAE for metallurgical slabs and to produce bulk products such as rolled plates and sheets. The new processing technology “ECAE + WR” (warm rolling) was demonstrated for aluminum armor alloy AA 5083. Depending on rolling reduction, yield stress (YS) and ultimate tensile strength (UTS) in large cross section products might be so big as YS = 480 MPa and UTS = 503 MPa for reduction more than 90% which exceed related characteristics of ordinary Temper H343 on 70% and 45%, respectively. Large billets of AA 5083 (15” x 15” x 3.2” of 32 kg weight) were ECAE’d at

temperature 250°C and rolled at temperature 150°C to plates 24” x 24” x 1” (Fig. 1). In this case, because of restricted reduction, the attained mechanical properties were YS = 397 MPa, UTS = 446 MPa, relative elongation RE = 10%. The blanks 12” x 12” x 1” of AA5083 were delivered to the U.S. Army Research Office for ballistic testing. With the increase of the billet size to 30” x 30” x 6.5”, practically available properties of armor plates will be UTS = 475 MPa for thickness 1” and UTS = 500 MPa for thickness 0.4”. On the other hand, bulk ultra-fine grained ECAE and ECAE+WR billets and semi-finished products of comparative low cost may find numerous structural applications owing of their superior properties and fabrication characteristics.

Figure 1

In the Optional Plan, fabrication characteristics of ECAE and ECAE+WR aluminum alloys AA5083 and AA5082 were considered for specific applications:

1. Superplastic forming. Processed ECAE+ WR AA5083 is recrystallized at 300C, 1h. With 75% rolling reduction, a grain size is just 2.5 microns. During annealing to temperature 500°C the grain size increases to 5.5 microns, and the material shows elongation more than 400% at strain rate 10^{-1} sec. Therefore, ultra-fine grained stable ECAE+WR AA5083 is the superior material for high temperature - high strain rate sheet forming operations in numerous applications.

2. Bulk precision forging. As superplastic bulk forming requires special equipment, thick blanks after ECAE and ECAE+WR can be used for precision forging of complicated components in dies at ordinary presses. Fig. 2 demonstrates a component with four thin long fins forged at temperature 400°C in a split die from the ECAE+ WR AA5083. The ultra-fine grained structure provided excellent formability and low forging load of 55t. For comparison, Fig.2 also presents a forging from the ordinary AA5083 with grain size 20 microns at similar condition and load 55t.

Figure 2

3. Sheet metal forming. It is also attractive to use the annealed ECAE+WR light alloys in ordinary sheet forming operations. Related technical feasibility was demonstrated for operation of cold cap drawing of sufficiently thick sheets which requires high workability. ECAE+WR alloy AA5083 after annealing 300°C, 1h was successfully drawn with drawing ratio D/d = 1.76 (D is a blank diameter, d is a cap diameter) and thickness/d ratio = 0.054 that could not be attained for other conditions. Even higher drawing ratio D/d = 1.97 was observed for ECAE+WR +anneal 275°C, 1h AA5082. See Fig.3.

Figure 3

4. Friction Steer Welding (FSW) of ECAE+WR AA5083 was performed for thickness 0.25”. A micro-structural analysis detected (i) weld area with fully recrystallized grains of 5-6 microns and hardness HRB = 15, (ii) heat affected area with partially recrystallized structure and hardness HRB = 40, and (iii) area of the original ultrafine structure with a few recrystallized grains and hardness HRB = 65. As it leads to significant degradation of structure and properties, fabrication of mono armor plates by ECAE+WR is the most desirable. An additional R&D work is necessary to reduce a heating effect of FSW and improve the weld uniformity.